RADCOM TECHNICAL FEATURE

The User Friendly Smith Chart

By *RadCom* Technical Editor Peter Dodd, G3LDO*

NEARLY EVERY MAJOR book on antennas has a description of a complicated circular graph known as a Smith chart, with instructions on how to use it. The Smith chart is very useful and is used by the professionals to design antennas and impedance matching networks. In spite of this I have never, in 37 years of amateur radio, met anyone who uses the Smith chart to solve a practical antenna problem. So why should this be? And what's wrong with the good old SWR meter for solving antenna matching problems?

THE SWR METER

THERE DOES NOT SEEM to be any problem with a general understanding of standing wave ratio (SWR). Even the most non-technical radio amateur is aware that the coaxial transmission line connecting the rig to the antenna has a characteristic impedance, which is around 50Ω; and that an SWR meter can be used to measure any 'standing waves' on the coaxial line caused by the antenna impedance having a different value to that of the coaxial line. In nearly every ham shack there is usually a SWR meter connected permanently into the coaxial between the transmitter and the antenna or antenna system.

The method of antenna adjustment using an SWR meter is well known. You connect up your antenna system then make a number of adjustments to the antenna and then see which one improves the SWR. This approach is fine with simple antennas such as dipoles. However, things don't always go smoothly. It is not unusual to hear: "I've tried everything but I can't get the SWR down". The setting up and adjustment of a gamma match on a beam, or matching network on a compact antenna can be quite frustrating if the only indication that you have is an SWR meter.

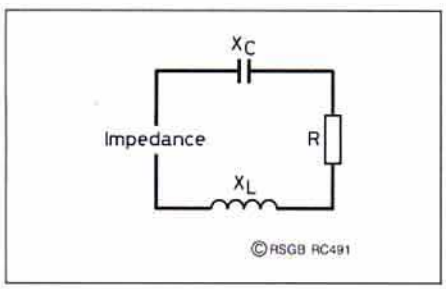


Fig 1: Equivalent antenna circuit

*37 The Ridings, East Preston, West Sussex BN16 2TW.

WHAT IS IMPEDANCE?

THE BEST WAY TO TELL what is happening at the feedpoint of an antenna is to measure its impedance directly.

Impedance (whose symbol is Z) is a general term, which can be applied to any electrical circuit that impedes the flow of AC current. An antenna is a tuned circuit having inductance, capacitance and resistance and an equivalent circuit is shown in **Fig 1.**

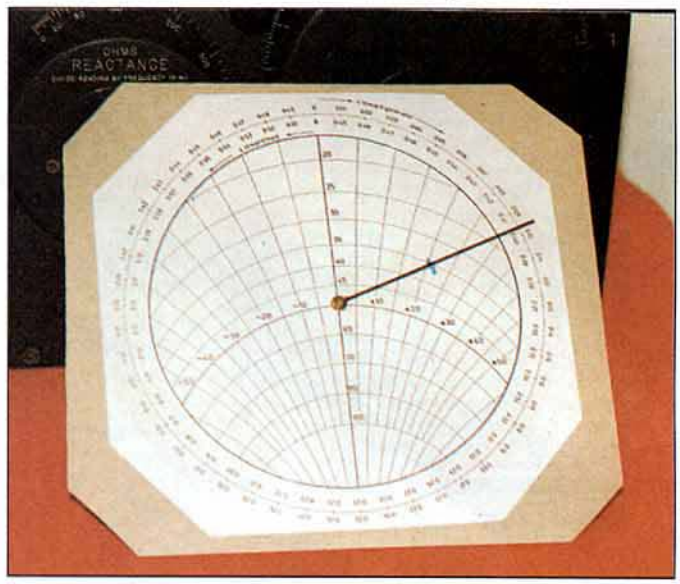
When transmitter power is fed to the antenna the current in the resistive part is in phase with the applied voltage; while the current in the inductive or capacitive part (reactance) is 90 degrees out of phase with the applied voltage. Thus the phase relationship between current and voltage in a tuned circuit or antenna element can be anything between zero and plus or minus 90 degrees, depending on the ratio of resistance and reactance.

Because of this, impedance is always expressed in two parts; resistive and reactive. An impedance having an resistance of 75Ω and a inductive reactance 50Ω is conventionally written as:

75 +j50

The j symbol bothers a lot of people. This is probably due to the way it is described in literature as "the square root of minus one" or "imaginary". Furthermore, impedance is described as "complex". All these terms are derived from the mathematics used in impedance calculations. For our consideration of impedance, j can simply be regarded as a convention for reactance. The '+j' indicates inductive reactance and a '-j' indicates capacitive reactance. When the antenna is at its resonant frequency the +j and -j parts are equal and opposite so only the resistive part remains.

An impedance value can be plotted as co-ordinates on a rectangular chart or map in just the same way that a QTH longitude and latitude is plotted on a map. A position of, say, 52°N 3°E would be plotted on a map as shown in **Fig 2**. Our impedance value of 75 +j50 would be plotted on an impedance map or chart as shown in **Fig 3**. On the impedance chart we use + or -j instead of E or W longitude.



General construction of the Smith chart calculator.

IMPEDANCE MEASUREMENT

BEFORE WE CAN MAKE full use an impedance chart we need an instrument for determining a position on the chart. A simple instrument for measuring impedance was described by Ed Chicken G3BIK [1]. A even simpler and more accurate impedance measuring technique, known as the 3-Meter

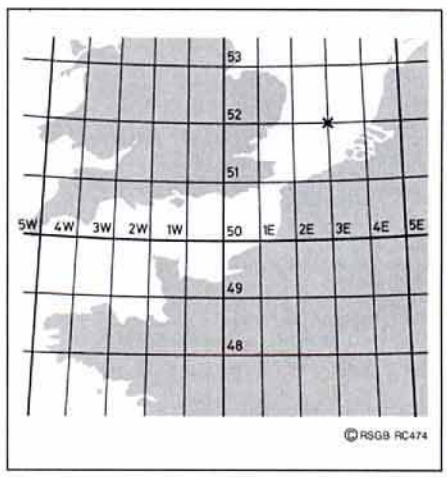
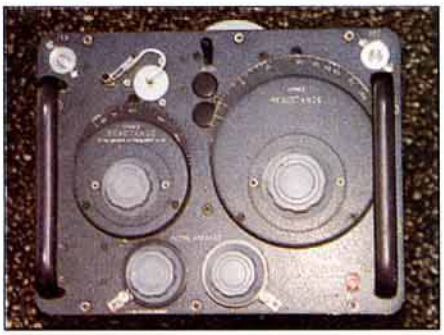


Fig 2: Map showing co-ordinates of latitude and longitude.



General Radio 1606 impedance bridge, showing the resistance and reactance scales.

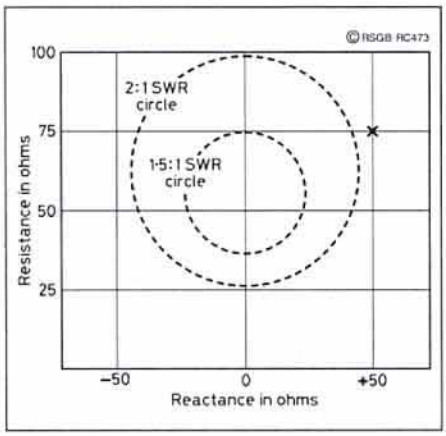


Fig 3: Impedance map showing co-ordinates of resistance and reactance.

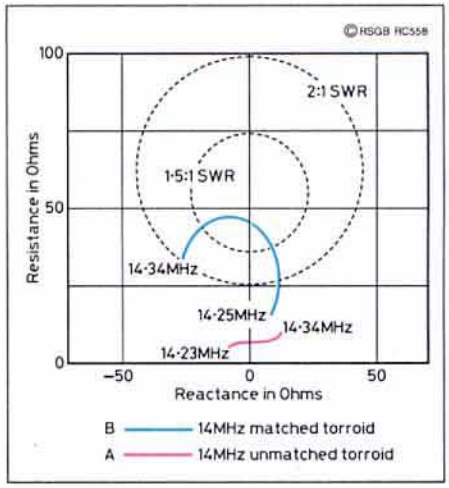


Fig 4: Impedance 'signatures' of a double toroid antenna.

method, is described in *The Antenna Experimenters Guide*, available from the RSGB, see page 90.

A professional impedance bridge is shown in the above photo. As you can see there are two calibrated controls, one for R and the other for j. Information from the calibrated dials on the instrument can be used to establish the impedance position on the chart.

The chart in **Fig 3** also illustrates the limitations of SWR as a means of determining the characteristics of the feedpoint of an antenna. The two circles shown in Fig 3 are circles of constant SWR, one for 2:1 and the other for 1.5:1. Using our map analogy they can be regarded as SWR contours. When you measure SWR to try to find out what is going on at the antenna you are measuring the effect of the antenna not having the same value of impedance as the antenna. However, an impedance of 100 +j0 would give the same SWR as an impedance of 25 +j0. You will see that there is a large number of impedance values that can give an SWR of 2:1. If you measure an SWR value of 2:1 then all you know is that you are somewhere on the 2:1 circle. This explains why an SWR meter is not necessarily the best instrument for adjusting an antenna with a matching network such as a Gamma match.

If you make several impedance measurements of an antenna over a range of frequencies they can be used to produce an impedance 'signature' of the antenna. **Fig 4** shows two of these signatures, which were obtained when evaluating the G2AJV double toroid antenna [2]. Plot A shows that the resistance is around 8Ω at resonance, and explains why no amount of antenna pruning would bring the SWR value to usable proportions. With a suitable matching circuit, the impedance is very close to 50Ω at resonance as shown in plot B.

(Resonance is where the inductive and capacitive reactances in a tuned circuit or antenna element are equal and opposite, and this condition exists only on the 0 reactance vertical line of Figs 3 and 4)

To obtain the results shown in Fig 4 it is necessary to measure the antenna feedpoint impedance at the point where the coaxial is connected to it. There are many practical difficulties in doing this and it is much more

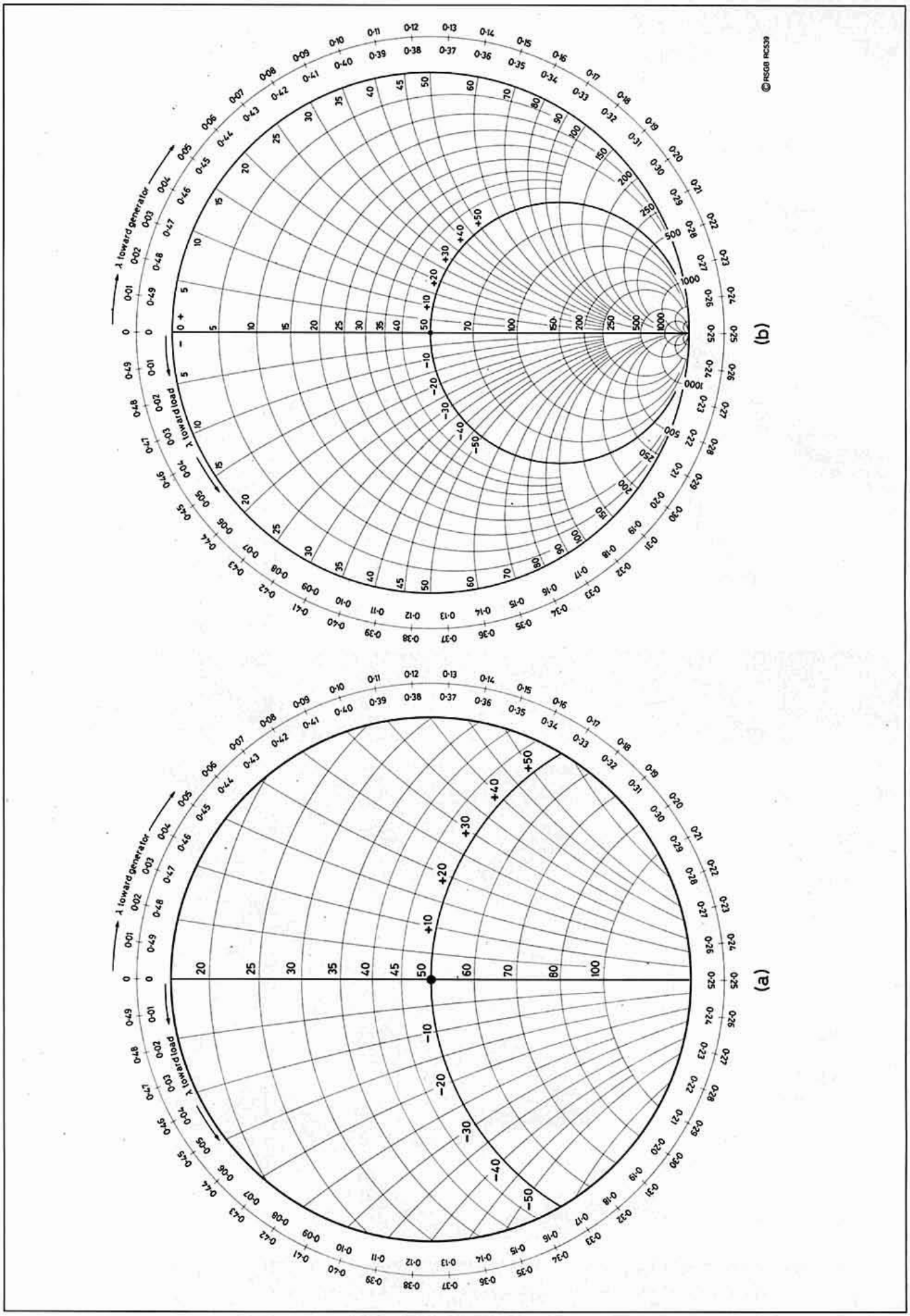
What Would You Do if You Woke to Find This?

● STOLEN from Lincoln area: Yaesu FT-990 S/N 1K080232; digital Message Unit S/N A00470002; Yaesu FT-480R S/N 0K050309; Yae[illegible]/N

● STOLEN from the Goole Radio and Electronics Society: Yaesu FT730R (S/N 3C060105); Yaesu FT230 (S/N 4C220005); Cleartone Commando 4m FM crysta[illegible]

● STOLEN from Brunel University ARS shack in Feb: Yaesu FT101Z (S/N OM230118); Heathkit SB220 linear; Honda 300E petrol Generator and an Icom EC275H 2m tr[illegible]iv

Radio Society of Great Britain
Lambda House, Cranborne Road, Potters Bar, Herts EN6 3JE



Smith charts for constructing the calculator.

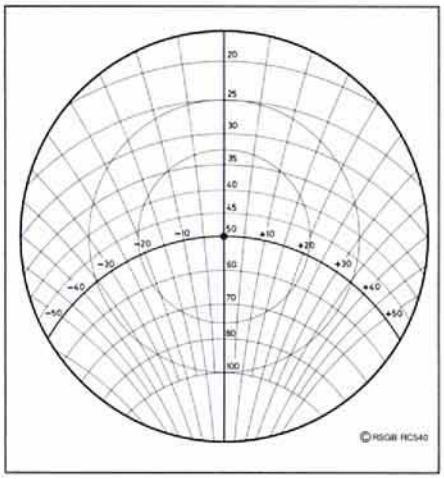


Fig 5: Basic simplified Smith chart.

convenient if impedances could be measured via a length of coaxial cable. Now while SWR is the same anywhere along a transmission line (neglecting any losses) the measured impedance at one end depends on the transmission line electrical length. This is where the Smith chart comes in.

The Smith chart, shown in **Fig 5** is an impedance map similar to the ones shown in Figs 3 and 4. It can be considered as just a different projection, just as maps have different projections, such as the Mercator Projection or the Great Circle projection. The most obvious difference with the Smith chart is that all the co-ordinate lines are sections of a circle instead of being straight.

The Smith chart, by convention, has the resistance scale decreasing towards the top. With this projection the SWR circles are concentric, centred on the 50Ω point, which is known as the prime centre.

If you are familiar with a normal Smith chart you will recognise that the one shown in Fig 5 is simplified. The differences and the reasons for simplification are described later.

One advantage of the Smith projection is that it can be used for calculating impedance transforms over a length of coaxial feeder. Because the reflected impedance varies along the feeder it follows that you need to know the electrical length of your coaxial feeder to the antenna. You can then calculate the transform of impedance measured at the shack end of the feeder using the noise bridge.

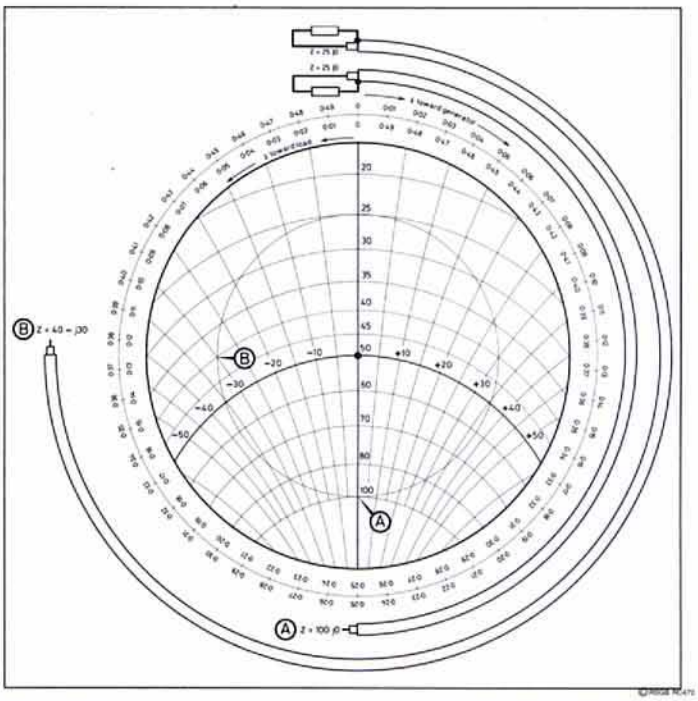


Fig 6: Smith chart, with transmission line electrical length scale, superimposed on two lengths of coaxial cable.

The impedance transformation Smith chart is illustrated in **Fig 6**. An additional scale is added around the circumference, calibrated in electrical wavelength. Halfway round the chart equals 0.25 or quarter wavelength, while a full rotation equals 0.5 or half wavelength.

Two lengths of 50Ω coaxial feeder are shown superimposed around the circumfer-

. . . Don't be Caught Out, Contact ARIS Now!

And Protect Your Shack

If your gear was stolen, would your household insurance cover it *all*? For RSGB members only, ARIS offers a tailor-made insurance for your *entire* station, including antennas. The standard policy offers **'new for old'**, replacing your gear with the same or similar, or paying the full cost of repair; there's no 'wear and tear' clause. You can even include home built and mobile and portable stations. What would *you* do if you awoke to the scene on page 41? Call ARIS now before it's too late!

For more information contact Amateur Radio Insurance Services on 01342 84 4000, or write to Shepheards Hurst, Green Lane, Outwood, Surrey RH1 5QS.

Radio Society of Great Britain
Lambda House, Cranborne Road, Potters Bar, Herts EN6 3JE

ence of a Smith chart in Fig 6; one length quarter wave long and the other 3/8 wavelength). Both lengths are connected to a load having an impedance of 25 +j0. The quarter wave length of line (0.25) gives a measured impedance of 100 +j0 at the other end while the 3/8 section (0.375) gives an impedance of 40 +j30. It can also be seen from Fig 6 that a halfwave length of coaxial cable would transform the impedance back to 25 +j0.

A PRACTICAL SMITH CHART CALCULATOR

YOU CAN USE EITHER of the charts on Page 42 to construct a Smith chart calculator.

Chart (a) has a restricted impedance range but is easier to use. It is used where the impedance excursions are limited and do not cause an SWR much greater than 2.5:1.

Chart (b) is the standard chart which covers impedances from (theoretically) zero to infinity.

For this exercise we will make an impedance calculator using the restricted range chart, which is easier read and use, see the photograph on page 40.

Make a photocopy of the chart enlarging it to bring it to a usable size. I suggest an enlargement from A4 to A3; a single chart will then fit on a single piece of A4 paper. The chart is then glued to a circular sheet of stiff cardboard or thin aluminium. A small hole is drilled in the chart and backing material at the 50 +j0 point.

From a piece of very thin perspex or transparent plastic or celluloid cut a circle the same size as the chart to make an overlay. A hole is then drilled exactly at the overlay centre. Identifying the centre point should be no problem if a pair of compasses is used to mark the overlay before cutting.

Make a cursor by drawing a line along the radius of the overlay, using a fine tipped marker pen. Cover the line with a strip of cellotape to prevent the line rubbing out. Trim off the excess tape.

Fix the transparent overlay to the chart with a nut and bolt with the tape covered line against the chart. Adjust the nut and bolt so that the overlay can be easily rotated, as shown in the photograph.

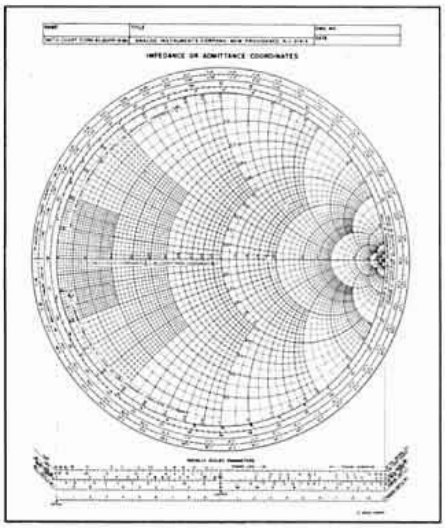


Fig 7: View of a normalized standard Smith chart.

USING THE CALCULATOR

THE USES TO WHICH this calculator can be put are too numerous to be included in this article. But here are three examples.

MEASURING COAXIAL CABLE ELECTRICAL LENGTH

YOU CAN FIND THE electrical length of coaxial cable by physically measuring its length and multiplying it by the cable velocity factor.

A more accurate method is to measure the electrical length directly using an RF impedance measuring instrument (eg a noise bridge). It also assumes there are no cable losses; in practice this means that the procedure will only work with relatively short lengths of fairly good quality coaxial cable. You should be using reasonable grade coaxial anyway to measure antenna characteristics - even SWR.

1 Terminate the load (antenna) end of the cable with a 22Ω resistor.
2 Measure the impedance at the other end of the feeder.
3 Move the cursor so that it intersects the measured impedance point. The cursor will now point to the electrical wavelength of the feeder marked on the outer scale marked 'wavelengths towards generator'.

The cable may be several half wavelengths and part of a half wavelength long. The Smith chart will only register the 'part of a half wavelength', which is all we are interested in regarding the impedance transform effect.

CALCULATING ANTENNA IMPEDANCE

THIS IS A METHOD of calculating antenna impedance from a measured impedance value, using coaxial cable whose electrical length has already been determined.

1 Connect the cable to the antenna.
2 Measure the impedance at the other end of the coaxial.
3 Move the cursor over the measured impedance point and mark the point on the overlay with a wax pencil.
5 Follow the cursor radially outwards to the scale marked 'wavelengths towards load'. Write this number down.
6 Add the length of cable in wavelengths to this number.
7 If the number is larger than 0.5, subtract 0.5.
8 Rotate the overlay until the cursor points to this number on the 'wavelengths towards load' scale.
9 The antenna impedance will be found on the cursor directly under the wax pencil mark.

EXAMPLE

The measured impedance is 35 +j20Ω and the cursor points to 0.407 on the 'wavelengths towards load' scale.

The cable electrical length was measured as 0.13 wavelengths.

Then 0.407 + 0.13 = 0.537 wavelengths. Off scale - too big! So subtract 0.5 wavelengths = 0.037 wavelengths.

Rotate the overlay until the cursor points to 0.037 on the 'wavelengths towards load' scale.

The antenna impedance is shown as 28 -j8Ω under the cursor at the same radius as the measured impedance.

MEASUREMENT OF SWR

CALCULATION OF SWR is very simple using the Smith chart. The result is useful for correlating impedance measurements with SWR measurements. To measure SWR:

1 Move the cursor over the measured impedance point.
2 Mark the point on the overlay with a wax pencil.
3 Move the cursor to the 0 point on the outside scales.
4 The SWR can be read off as 50 divided by the mark on the cursor. The impedance measured above gives a reading of 27 +j0. 50 divided by 27 equals 1.85; the SWR in this case is 1.85:1.

You can, of course, calibrate the cursor in SWR. Just place the cursor in the vertical zero position and place marks on the cursor at the 33.3, 25 and 20 resistance points to give SWR marks at 1.5:1, 2:1 and 2.5:1 respectively.

CONCLUSION

USING THE SMITH CHART, as described above, doesn't seem so complicated, so why is it not more widely used?

It is probably because the Smith chart is designed for professional use and is required to have high resolution to give accuracy to the results. Like any graphic aid, the higher the line density the greater is its resolution but the harder it is to read as you can see in **Fig 7**.

In addition most Smith charts are 'normalized' so that they can be used at any impedance and not restricted to 50Ω, as are the ones described in this article. This is achieved by assigning 1 to the prime centre; other values, for example, are 0.5 for 25Ω and 2 for 100Ω in a 50Ω system.

NOTE

YOU COULD OBVIOUSLY measure the impedance of the antenna using a halfwave, or a multiple of a half wavelength, of coaxial cable and dispense with the Smith chart altogether. In fact this is often done but there are a couple of disadvantages. Because the cable is resonant it can result in antenna currents on the cable, which can give inconsistent impedance measurement results. Also if you make several impedance measurements over a range of frequencies remember that the cable is a half wavelength long on one frequency only.

ACKNOWLEDGEMENT

TO PETER SWALLOW, G8EZE, for checking the manuscript and help on a procedure for using the Smith chart.

REFERENCES

[1] 'Tone Modulated HF Impedance Bridge', E Chicken, G3BIK, *Radio Communication*, June/July 1994.

[2] 'Evaluation of the G2AJV Toroidal Antenna', Peter Dodd, G3LDO, *Radio Communication*, August 1994. ♦